IRISH FISHERIES INVESTIGATIONS

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ABSTRACT

The spawning of pike was studied in 1965 and 1966 in five large Irish limestone lakes—Loughs Sheelin, Ennell, Mask, Corrib and Arrow. The spawning period was found to be February to April. Spawning took place in shallow, sheltered situations where there was a carpet of dead or living vegetation on the bottom at a depth of 20 to 60 cm. Spawning took place by day, at a water temperature of at least 9°—10°C, when lake levels were high or rising. Gill-net catches reached a peak during periods of spawning. Weather conditions in February and March were much milder in 1966 than in 1965, and spawning began about a month earlier than in 1965.

The eggs of Irish pike are 2.7 to 3.0 cm in diameter. They are golden to honey coloured, with a great many minute oil-globules distributed through the yolk in numerous tiny clusters. The incubation period in the field is probably 8—14 days, and the newly hatched larva is 8.0—9.0 mm long. For the first 10 days or so, the larvae hang vertically from the vegetation by means of adhesive glands on the head. They then become free-swimming, and soon afterwards begin to feed. At this stage they measure 13.0—13.5 mm. Their first food consists of small cladocera and copepods. Later, they feed on larger cladocera, amphipods, isopods, young stages of aquatic insects, and fish fry.

INTRODUCTION

The pike, *Esox lucius* L., is not native to Ireland (Went, 1957) but its introduction dates back many centuries and it is now widespread in the catchments of many Irish rivers.

Healy (1956) has shown the necessity for reducing the numbers of pike in trout lakes in order to maintain trout stocks. Since 1952, the Inland Fisheries Trust has been engaged in the development of selected Irish lakes for trout. Many of these lakes hold pike. In small lakes it was found that only complete or virtually complete eradication of pike by means of rotenone enabled trout to survive in adequate numbers to provide good fishing. In the big Irish limestone lakes, however, it is possible by means of gill-nets, long-lines and wire traps to reduce pike stocks sufficiently to bring about a substantial increase in the numbers of trout.

Adult pike in the big lakes are taken mainly in gill-nets during the spawning season. Wire traps are used to reduce the numbers of young (6 to 18 months old) pike. In recent seasons "spot" treatment of pike spawning areas with rotenone has proved a useful method of reducing the numbers of pike fry a few weeks old.

This paper gives the results of research carried out into the biological background to the annual spring programme of pike control measures in the big Irish limestone lakes. It covers studies of the spawning sites selected by pike, the relationship between lake levels and temperatures and spawning, the relationship between spawning times and gill-net catches, the development of the eggs, and the habitat, food and growth of the young pike.

SPAWNING INVESTIGATIONS

In the spring of 1965, pike spawning studies were carried on in four large Irish limestone lakes—Loughs Sheelin (Counties Cavan, Meath, Westmeath), Mask (Co. Mayo), Corrib (Co. Galway), and Arrow (Co. Sligo). The studies were repeated in 1966 in the same four lakes and also in Lough Ennell, Co. Westmeath.

All these lakes are shallow in proportion to their surface area. In Loughs Corrib and Mask, there is a trench near the western shore where the depth exceeds 150 feet, but most of the water is very much shallower. In Lough Ennell, the maximum depth is about 90 feet, and Lough Sheelin is shallower still. The west shore of Lough Mask and the north-west shore of Lough Corrib are bordered by high land and acid rocks, but the lakes themselves lie on the carboniferous limestone. The other lakes lie on the limestone and are surrounded by it, though there are patches of bog and glacial drift. All five lakes have stretches of stony shore and areas of emergent vegetation, mainly *Schoenoplectus lacustris, Phragmites communis, Carex spp* and *Equisetum spp.* The lake bed consists variously of rock, stones, sand, marl and mud, according to depth and exposure. There is a rich invertebrate fauna. There is no marked thermal stratification in summer to depths of under 50 feet and there is no deoxygenation of the deeper water layers, even though productivity is high.

Table 1 gives further details of the five lakes concerned.

TABLE 1

Lake	*Area (Acres)*	*Alkalinity*	*Conductivity*	*pH*	*Fish Present*
L. Sheelin	4,600	3.25 (March) 2.65 (Sept.)	317.5 (March) 267.5 (Sept.)	8.5	Brown trout *Salmo trutta* L.; pike *Esox lucius* L.; perch *Perca fluviatilis* L.; rudd *Scardinius erythrophthalmus* (L.); bream *Abramis brama* (L.); tench *Tinca tinca* (L.); eels *Anguilla anguilla* (L.); and sticklebacks *Pygosteus pungitius* (L.).
L. Ennell	3,450	4.6 (Sept.)	423 (Sept.)	—	Brown trout; pike; perch; rudd; eels; sticklebacks.
L. Arrow	3,100	2.45 (Sept.)	244 (Sept.)	8.45	Brown trout; pike; perch; bream; eels; sticklebacks.
L. Mask	20,496	1.85 (Sept.)	218 (Sept.)	8.3	Brown trout; char *Salvelinus alpinus* (L.); pike; perch; eels; sticklebacks.
L. Corrib	41,617	1.8 (Sept.)	205 (Sept.)	7.8	Brown trout; salmon *Salmo salar* L.; char; bream; rudd; eels; sticklebacks.

Alkalinity = bicarbonate alkalinity in milliequivalents.
Conductivity = conductivity in reciprocal megohms per cm^3 at 20°C.

Methods

In each of the lakes studied, a known pike spawning area was selected, and a stake with a graduated marker was placed in position in it. A submerged maximum/minimum thermometer was attached to the stake. Depth and thermometer readings were taken, for the most part daily, by Trust field staff.

When pike were observed spawning, the fact was noted, and the precise position or positions usually fixed by a marker. The depth at the actual place of spawning was noted. Eggs were collected by means of hand nets and samples of the bottom material were collected for identification. Eggs and/or fry were sought at intervals thereafter. Any subsequent spawnings observed were also noted.

Some weeks later, the spawning areas were treated with rotenone and samples of the "kill" preserved for measurement and examination for food.

In addition, in the case of each lake, a note was kept of the first date on which female pike with running roes were taken in the nets and also of the last date on which unspawned females were captured.

The actual experimental areas were not netted, i.e. pike were allowed free access to spawn. Weekly records of catches of pike in the gill-nets elsewhere on the lakes were kept, and compared with the data on spawning. The gill-nets take only pike of mature size and, for all practical purposes, only pike moving into, around, or out of spawning areas.

Weather Conditions in 1965

Claremorris is the nearest weather recording station to the three western lakes investigated (Loughs Mask, Corrib and Arrow) and Mullingar the nearest to Lough Sheelin.

The Meteorological Office supplied data as to monthly precipitation, mean monthly air temperatures and average daily duration of bright sunshine, for each of these stations for the years 1955 to 1964 inclusive, and for the early months of 1965. The figures for the two stations did not differ greatly, though spring temperatures in Claremorris were a little higher, on average, than at Mullingar. The rainfall was also somewhat higher at Claremorris.

At both Claremorris and Mullingar, as indeed in Ireland as a whole, rainfall is usually high in December and January. February rainfall figures show considerable fluctuations from year to year but, on average, rainfall in February is less than in November and December and in some years there is less rain in this month than during the summer. March is usually a month of low rainfall.

The general level of Irish lakes in early spring, therefore, is largely dependent on the December and January rains. Rainfall in February

would tend mainly to maintain rather than increase general levels, while rainfall in March, which is sporadic rather than protracted, would mainly cause temporary rises in levels whose general tendency at the time is to fall gradually.

In Ireland, temperatures in the early months of the year are, on average, well above freezing point. At Mullingar, for example, mean monthly air temperatures are: January 4.3°C, February 4.9°C, March 6.8°C, April 8.8°C. Only in unusually severe winters, therefore, does ice form on the lakes to a significant extent while melt-water from snow makes only an occasional and minor contribution to lakes and rivers.

The situation on Irish lakes is, therefore, different in some respects from that in many European and Canadian waters in which pike occur.

In 1965, January rainfall was about average, while the temperature was 1.6°C below average (2.7°C at Mullingar, 3.1°C at Claremorris). February was particularly dry (only 13.0 mm precipitation at Claremorris), and rather cold (3.1°C at Mullingar, 3.2°C at Claremorris). Both January and February were characterised, however, not so much by low mean temperatures, as by rather persistently low daily temperatures, with rather less fluctuation than usual between cold wintry spells and mild spring-like periods. The mean monthly air temperature for March, 1965 was not especially low (5.5°C at Mullingar; 5.6°C at Claremorris). The mean monthly temperature does not, however, truly express conditions during this month. In fact, March began with a countrywide snowstorm and the weather during the early part of the month was very severe. Towards the middle of the month, it became less cold, and there were some misty days. This was followed by some heavy rain (total precipitation for the month was 87.2 mm at Mullingar, 87 mm at Claremorris). Temperatures rose during the latter part of the month and towards the end of the month there began a spell of very mild weather, with warm air, bright sun and high temperatures.

There are indications that the cold snap early in March delayed spawning, and also reduced the duration of the spawning period.

Lough Sheelin, 1965

The station selected for observation of pike spawning was Cummiskey Bay, a small, sheltered inlet behind the public boat harbour at Kilnahard, on the north shore of the lake.

On February 25, when readings began, the depth of water on the marker was 52 cm. Levels declined progressively to about March 12, when the reading was 30.5 cm and they remained at that level until March 20, when they began to rise again, reaching a crest of 44.5 cm during the three days March 29—31, and then dropping slowly and progressively to 29 cm by May 5. There was another small rise towards the middle of May (maximum 38 cm on May 10 and May

12), following which there was a progressive fall down to 20.5 cm on June 4.

The maximum and minimum water temperatures on February 24 were 7.2°C and 2.2°C respectively, and thereafter temperatures trended downwards, the lowest maximum temperature (3.3°C) being recorded for March 3 and 4, and the lowest minimum temperatures (0°C) for the same dates. Maximum temperatures of 8.3°C to 8.9°C were recorded at varying dates between March 18 and March 28, but night temperatures were low (5.0°C to 6.1°C) during this period.

On the night of March 27, the minimum water temperature was 5.5°C. The following day, a maximum temperature of 12.2°C was recorded, the night temperature again falling to 5.5°C. On March 29, the temperature rose to 13.3°C, and that night was relatively warm, the minimum temperature being 8.9°C. The next day, March 30, was warm and sunny, and the temperature rose to 15.5°C. Spawning took place that afternoon for the first time, though pike had been seen moving about the bay for some days previously.

On the night of March 30, water temperatures fell to 5.5°C and no spawning took place the following day. On April 1, however, when temperatures rose to 12.7°C, spawning again took place in Cummiskey Bay—and also in Gaffney's Bay, on the south shore of the lake.

Spawning took place in flooded, sedgey situations in depths of 20 cm to about 60 cm. Eggs were collected on April 1 in the places (marked) where spawning was observed in Cummiskey Bay. They were adhering to *Fontinalis sp.* moss.

No subsequent spawnings were observed. On April 15, pike alevins, some of which appeared to be about 4 days old, were hand-netted in the marked areas in Cummiskey Bay, together with alevins of 10-spined sticklebacks. This would indicate an incubation period of 10—12 days, depending on which of the two spawnings (March 30 or April 1) yielded the pike alevins.

On May 11, Gaffney's Bay (where spawning was observed on April 1) was treated with rotenone, and yielded O-group pike ranging from 2.5 to 2.8 cm, together with yearling pike ranging from 20.5 cm to 26.3 cm fork length, 21.8 cm to 28.2 cm total length. The O-group pike were approximately 4 weeks hatched.

On June 30, Cummiskey Bay was treated with rotenone and yielded O-group pike approximately 11½ weeks hatched. They ranged from 7.0 to 14.4 cm in total length, the modal length being 11.5 to 12.4 cm. They contained perch fry and bottom invertebrates.

Gill-net catches in Lough Sheelin were poor during the week ending March 6, but increased progressively in subsequent weeks, reaching a peak during the week ending April 3 (during which spawning took place). Thereafter, they declined rapidly and had become negligible by mid-May.

Lough Mask, 1965

The selected observation site was a small flooded bay near Cushlough on the east side of the lake.

When recordings began on February 20, the water level on the marker was 89 cm. Water levels declined until March 10, when the level was 42 cm. They remained steady for a few days, and then from March 15 began to rise again until March 28—29, when they reached 58.5 cm. Thereafter they declined rapidly until April 9 (43 cm); following which there were two minor rises to approximately 51 cm, in mid-April, and again about May 10. By June 2, the level had fallen to 22.5 cm.

During the period February 19 to 23, maximum water temperatures were 5.0°C to 5.5°C. Then they declined until March 1, when the maximum temperature was only 2.5°C. Thereafter, maximum water temperatures rose slowly, reaching 7.2°C to 7.8°C by mid-month. This rise in temperature took place while water levels were falling, or relatively low. On the night of March 21, water temperatures were down to 6.1°C. On the following day, water temperatures rose to 10°C, and spawning was observed for the first time on this day. At this time, water levels were rising and had risen about 12.5 cm since mid-month.

Spawning was again observed on March 26 and March 29, when maximum water temperatures were 9.4°C and 12.2°C respectively. These two spawnings coincided with the crest of the rise in water level which had occurred during the latter part of March.

No subsequent spawnings were observed.

An unspawned female pike was caught in another part of the lake (Maumtrasna Bay) as late as 24 May, 1965.

Spawning took place in the observation area in depths of 38 cm to 53 cm. Eggs deposited on March 22 were collected in a hand net in large numbers from the spawning site on March 25. They were scattered over and through a bottom carpet of grassy material, consisting for the most part of a mixture of a grass (*Agrostis stolonifera*) and *Juncus bulbosus* var. *fluitans;* with some *Apium inundatum* and *Mentha aquatica.* The fauna present included Corixids, Planarians and *Cloëon* nymphs.

A sample of 20 pike fry, approximately 7½ weeks hatched, was preserved for examination when the spawning area was treated with rotenone on May 23, 1965. The pike fry ranged from 3.9 cm to 6.4 cm in fork length; 4.0 cm to 6.7 cm in total length; and 0.43 to 1.95 grams in weight. The mean length was 5.2 cm fork; 5.4 cm total. The modal length was 5.1 cm fork, 5.3 cm total.

During the week ending February 20, 1965, gill-net catches in Lough Mask were high, but they declined sharply during the two

succeeding weeks, when lake levels and temperatures were falling. They rose progressively from the second week of March onwards and reached a peak during the week ending April 3. This corresponded to the third observed spawning. Catches subsequently again declined rapidly and became negligible towards the end of April.

Lough Corrib, 1965

The selected observation site was on the eastern side of the lake, near the Ballynalty stream.

When readings began on February 17, 1965, the depth on the marker was 43.5 cm. The level dropped until about February 24, when the marker showed 35 cm. Thereafter, it remained more or less steady until March 12, following which there was a rapid rise to 44.5 cm and thereafter an irregular rise to a maximum of 50 cm on March 27 to 29. Thereafter there was a fall to 38 cm in early April, a rise to 47 cm on April 14, a fall to 35.5 cm towards the end of April, a rise to 50 cm by May 7 and then a progressive fall to 29 cm by June 1. The fluctuations in water level were not of quite the same pattern as in Lough Mask, but it must be realised that Lough Mask discharges into Lough Corrib, which may therefore rise at times when Lough Mask is falling.

Water temperatures, as in Lough Mask, fell from the beginning of the recordings, with the onset of the cold snap. The lowest minimum temperature (−1.7°C) was recorded on the night of March 1, and the lowest maximum temperature (4°C) on the following day. Thereafter, maximuum temperatures trended upwards, reaching 11.6°C on March 21. Subsequently, temperature dropped again, the maximum on March 26 being only 7.8°C. This was followed by a sharp rise to 13.9°C at the onset of the fine spell (March 26). April maximum water temperatures fluctuated between 10.5°C and 15°C, while maximum water temperatures in May fluctuated between 14.5°Cand 21°C.

On March 18, 78 pike taken in the gill-nets in the eastern part of Lough Corrib included four females weighing 7250, 4000, 2700 and 1800g, from which the eggs were running freely. On March 27, two female pike were observed in the selected spawning area, but no spawning was observed. On the following day, a female and three males were seen moving about, but again no spawning was observed. On March 30, spawning was observed for the first time, and eggs were collected from the spawning site. The maximum water temperature was 13.9°C.

Ova were collected from the spawning area on April 5, 8, 12, 14 and 21. The last few samples, which were preserved, were opaque on examination and could not be cleared, but appeared to be in an early stage of development. Spawning therefore continued probably until the middle of April. The latest date on which an unspawned female pike was taken in the gill-nets was April 10.

Spawning took place in shallow water over a "grassy" bottom.

The spawning area was treated with rotenone on June 3, 1965 and yielded pike fry, probably about 8 weeks hatched. A small sample (7 fish) ranged from 5.3 cm to 6.9 cm in fork length, 5.6 cm to 7.2 cm in total length. The mean length was 6.1 cm fork, 6.4 cm total. They ranged in weight from 1.1 grams to 2.45 grams.

Gill-net catches in eastern Lough Corrib were rising during the fortnight ending February 27, but declined with the onset of the cold spell. They rose rapidly again during March, reaching a peak during the week ending March 20. There was a decline during the week ending March 27, but there was another peak the following week during which the first observed spawning occurred. Thereafter, catches progressively declined, and had become quite small by April 24.

Lough Arrow, 1965

Water level readings began on March 21, and continued until June 7. During this period, the fluctuations in level were relatively small. The marker readings rose from 43 cm on March 21 to 53 cm (highest recorded level) on March 25; declined to 46 cm in early April; rose again to 52 cm in mid-April and declined slowly again, with minor intermittent rises, to 37 cm on June 7.

Maximum temperatures were down to 5.5°C on March 22, and during the next three weeks reached or exceeded 10°C only on March 29—30, April 5—6, April 8, and April 10. The highest water temperature recorded was 11.1°C. A temperature of 10°C was recorded on April 14; 11.1°C on April 19—20 and 10°C on April 21. Temperatures rose towards the end of April, and reached values of over 15°C during May.

The Lough Arrow site was, perhaps, more exposed than the sites on the other lakes. Pike spawning begins, by local estimates, later in Lough Arrow than in Lough Mask or Lough Corrib. The weather in late March and April on Lough Arrow was generally rough and cold, and it was a "late spring". The first female pike with running roe was taken in the gill-nets on March 31, 1965.

No spawning was actually observed in the area selected but a sample of bottom material, collected there on April 16, 1965, was found, on examination some days later, to contain a few pike eggs, recently deposited. The material in question comprised mud with an admixture of broken reed (*Phragmites sp*) stem and odd bits of *Littorella sp*—i.e. it came from a bottom which could be described as broken "reed mat" lying on mud. The fauna present included many cased caddis larvae, numerous snails (*Limnaea pereger, L. stagnalis, Hydrobia sp, Bithynia sp, Valvata sp, Planorbis sp.*) bivalves (*Sphaerium sp*), *Asellus sp, Gammarus sp,* and Corixids.

The latest date on which an unspawned female pike was taken in Lough Arrow was April 26.

The observation area was treated with rotenone on May 19—20, 1965 but yielded only adult pike, small perch and eels.

Catches of pike in gill-nets in Lough Arrow were small up to late March but high during the weeks ending April 3 and April 10, following which they declined rapidly.

Spawning Investigations in 1966.

For corroborative purposes, the pike spawning studies were repeated in 1966 in Loughs Sheelin, Mask, Corrib and Arrow and were extended also to Lough Ennell (Fig. 5).

In 1966, the weather in February and March was much milder than in 1965. The cold snap, in fact, came in mid-April, when snow fell, though it was not followed by frost.

As might have been expected, spawning took place earlier in 1966. In Lough Corrib, for example, spent female pike were taken in the gill-nets as early as February 14 and spawning was observed in the investigation area on March 3 and 4 (spawning was not observed until March 30 in 1965). In Lough Mask, most pike taken in the gill-nets were spent by mid-March. The latest date on which a gravid female pike was taken in Lough Arrow was April 29.

As in 1965, spawning in all the lakes studied was associated with high or rising lake levels, and maximum water temperatures of at least 9—10°C. Also, as in 1965, weekly gill-net catches showed peaks corresponding with inshore movements of spawning pike.

EGGS AND YOUNG STAGES OF IRISH PIKE

On the Continent, pike are artificially propagated. Gravid pike are trapped and stripped and their eggs artificially fertilised. The eggs are hatched in Zug jars which, in essence, are inverted, bottomless bottles. Water enters below, at the narrow mouth of the jar, and overflows at the top. The eggs, which have a higher specific gravity than water, are kept circulating in the jar by the current but do not pass out with the overflow. However, dead eggs, which have a lower specific gravity than healthy fertile eggs, can be separated out and removed by temporarily increasing the flow of water sufficiently to lift them up and over the rim of the jar. The alevins or sac fry are placed in trays through which water flows and when the yolk sac is nearly absorbed, the young pike are stocked out in ponds, in which an abundance of live food has been ensured by prior fertilisation.

A good deal of data on the eggs and young stages of pike is given in such standard works on fish culture as those by Huet (1960) and

Schäperclaus (1961). The larvae, post-larvae and fry have been described and figured by Gihr (1958). More information is therefore available about the eggs and young stages of pike than about those of many other coarse fishes.

As part of a general programme of research into the biology of Irish coarse fishes by the Trust, pike eggs were hatched and the sac fry reared on a number of occasions. The ova were stripped from gill-netted pike and artificially fertilised. They were hatched in plastic dishes measuring 30 x 20 cm, filled with water to a depth of about 5 cm and aerated by means of a diffuser attached to the air-line of an electric aquarium pump. The alevins or sac fry were reared in the same dishes. Material (ova, alevins and young pike) obtained in the field was also examined. In general, the Irish material agreed with that described by workers in other countries.

Ova.

Pike ova are translucent, golden to honey-coloured, with a perivitelline space (space between capsule and yolk) of moderate size. There are a great many minute oil-globules distributed throughout the yolk in numerous tiny clusters. The dimensions of artificially-fertilised eggs used in laboratory studies on Irish pike were as follows:—

Lough Owel (Co. Westmeath), 1964. Capsule 2.75 mm; contained yolk 2.3 mm.

Lough Mask, 1964. Capsule 2.8—3.0 mm.

Lough Sheelin, 1959. Capsule 3.0 mm.

Ova collected in the field during the pike spawning studies in 1965 and 1966 ranged from 2.8 to 3.0 mm in diameter. They were thus somewhat larger than the Continental eggs described by Schäperclaus (1961), which were 2.5 to 2.8 mm in diameter. Their dimensions also exceeded those of eggs of Windermere pike, which are 2.6 to 2.9 mm in diameter, mean 2.8 mm (Frost and Kipling, 1967).

In the early stages of development, the germ cap shows, to the naked eye, as a less transparent yellow patch deeper in colour than the yolk. Live uninjured eggs can, however, be described in general as being clear and golden. The appearance of white patches (coagulated yolk), or the development of cloudiness or opacity, means the eggs are dead.

Incubation Period.

Schäperclaus gives the incubation period at 8°C as 80 day-degrees (10 days) to the eyed stage and 120 day-degrees (15 days) to hatching. Huet gives the average duration of incubation as 120 day-degrees, the variation being 95 to 150 day-degrees. The embryo can be distinguished at 30-day degrees. Eggs will withstand transport within 8 hours of fertilisation (corresponding to the "green ova" stage in trout); and, again, after 70 day-degrees of incubation.

A sample of pike eggs fertilised at Lough Sheelin on March 2, 1961 and incubated in Zug jars at the local field station was transferred to Dublin on March 11. The ova were placed in shallow dishes of water, and hatched on March 13 (11 days). Temperatures were not recorded.

Pike eggs fertilised at Mullingar at 12 noon on April 8, 1964, brought immediately to Dublin and placed in shallow dishes of water in an unheated laboratory, hatched for the most part on April 16 (8 days). Some continued to hatch up to April 20. Morning water temperatures in the laboratory, from April 8 to April 16, varied between 12—13°C, afternoon temperatures being about 1°C higher. Part of this sample, incubated in a saucer of water in the dining-room of the author's home, hatched on April 14 (6 days).

Early Development

Ova stripped from a Lough Owel pike at the Inland Fisheries Trust's station at Mullingar on April 8, 1964 (see above) were fertilised in accordance with Huet's recommendation viz. a completely dry dish was used and both male and female fish were wiped dry before stripping. The milt was squirted over the eggs and the latter stirred up with a feather. Water was then added to a depth of about 3 cm and the eggs left for about 3 minutes to swell and harden, after which they were completely washed. They were transferred to the laboratory within 2 hours in jars containing about ten parts water to one part eggs and placed in small numbers in 30 x 20 cm plastic dishes of water.

The eggs were fertilised at 12 noon. Some examined at 4.45 p.m. were at the 2-cell stage. By the following day, the germ cap was conspicuous. There was a tendency for the clusters of tiny oil globules to become more concentrated in the vicinity of the germ cap. On April 11 (3 days), the embryo was outlined. On April 13 (5 days) eyes, brain, notochord, and heart were clearly visible, and segmentation of the muscles was conspicuous. On April 14, the eyes were becoming pigmented. On April 15 the embryo was well advanced, moving, and wrapped round the yolk sac. Hatching began on April 16. The average temperature during the 8 days of incubation was about 13°C.

The majority of the alevins emerged head-first. As in the case of other fish, an enzyme appears to be produced before hatching, which makes the egg capsule thin and easily ruptured. None began to emerge sac-first, which as Schäperclaus observes, is fatal. Some, however, emerged tail-first. Schäperclaus considers such alevins will be viable. However, it was noticed, especially in the case of alevins whose hatching was delayed by several days after April 16, that some which emerged tail-first failed to get their heads and yolk-sacs free of the egg capsules. When some had been in this plight for more than a day, they were gently sucked into a pipette, and then gently blown out again. This freed them from the capsule, and they appeared to be unimpaired after this treatment.

A newly-hatched alevin examined on April 16, 1964 was 8.25 mm long. Schäperclaus gives lengths of newly-hatched larvae as 8.5—9 mm, Huet 8.0 to 9.0 mm, Frost and Kipling 7.5 to 8.0 mm. The Lough Owel ova were small by Irish standards, measuring only 2.75 mm, and the alevins hatched from them were, therefore, probably of less than average size. Big eggs would probably yield larvae 9 to 10 per cent larger i.e. up to 9.0 mm. The yolk-sac was large, round and clear golden-yellow, with numerous clusters of tiny oil globules. The heart, in lateral view, appeared to project partly into the yolk-sac. The head was inclined over the front of the yolk-sac. There was a wide marginal fin, beginning dorsally over the middle of the yolk-sac. The vent was located at approximately threequarters of the total length from the snout. There was no evidence of either the future median fins or pelvic fins, but large pectorals were developed. There was no trace of a swim-bladder.

A good deal of dark pigment had developed, even before the embryos hatched. In the newly-hatched larvae a dark line extended from the snout, through the eye, and along the side. By transmitted light, under magnification, the body generally appeared brownish-grey, with the notochord as a paler stripe. The brain was of a darker brown, with grey stellate pigment over the head and behind it. There was also a line of dark melanophores along the gut region. There was no pigment on the marginal fin. As compared with other coarse fish fry, the pike alevins were very dark and obviously adapted to live amongst vegetation rather than in open water.

The alevins could swim fairly well, with a rapid vibrating movement. They also clung to the sides of the dish, to weeds placed in it, and even to the underside of the surface film. They possess special adhesive organs on the head, in front of the eyes. These organs have been described and figured in detail by Georges (1964). They appear in the embryo (before hatching) about 6 days after fertilisation, when 55 to 60 somites have been formed. They disappear in the larvae about 10 days after hatching. The adhesive organs, the tendency of the fry to hang vertically in the water, and the dark length-wise camouflage stripes, are adaptations to clinging to vegetation in the spawning shallows before the filling of the swim-bladder. The early alevin stage is the Anheftungstadium (adherent phase) of Gihr (1958).

An alevin examined on April 17 (second day) was 8.5 mm long. The dark pigment along the gut region was denser, and there was a conspicuous dark patch at the vent(this was visible to the naked eye in dorsal view). The yolk-sac, though still large, was somewhat reduced.

On April 18 (3rd day) to naked eye, in lateral view, there was a conspicuous dark line along the side from the eye to the vent, with the dark patch at the vent forming a downward "quirk" to the end of it. The yolk-sac was more streamlined, and dark stellate pigment was developing over it.

On April 20 (5th day), the length had increased to 10.2 mm. The

mouth and gills were well formed, the yolk-sac more reduced and streamlined. The heart, in lateral view, was now largely clear of the yolk-sac, and a definite pericardium was formed in front of the sac. Dark stellate pigment was generally distributed over the body and brown stellate pigment over the yolk-sac. Dorsally and ventrally on the marginal fin, brownish pigment had developed, close to the body, at the site of the future dorsal and anal fins. Behind this, but quite distinct from it, near the tail, there was a patch of dark pigment specks on the marginal fin dorsally and ventrally.

On April 22 (7th day), the length had increased to 12 mm and the yolk-sac was much reduced. A well-developed patch of yellow-brown pigment replaced the brown pigment of the future dorsal fin of the 5th day larva and the patches of marginal fin pigment near the tail had become greyish-brown.

On April 24 (9th day) it was noticed that some of the pike alevins had become noticably lighter in general colour. A swim-bladder had formed, indicating that they had now entered the Freischwimmend phase of Gihr (free-swimming phase). The change in colour is, presumably, an adaptation to the change in habit and habitat—from clinging passively and vertically to weeds to swimming horizontally over the bottom.

On April 24, a fry which had been hatched at the author's home on April 14 (2 days older than the laboratory specimens and developed at a higher temperature) was examined microscopically. This example was 13.5 mm long. The yolk-sac, still containing bright yellow yolk, was much reduced, and merged into the general body outline. The swim-bladder was large. Small pelvic fins were developed. The marginal fin was still of more or less uniform height but fin rays were developing in the dorsal and anal fins. The general colour was brownish, with a good deal of blackish stellate pigment distributed generally over body and yolk-sac. Aggregation of black pigment formed little patches on the dorsum—level with the middle of the swim-bladder, the end of the yolk-sac and between the pelvics and the vent. The dark stripe effect on the anterior part of the body had faded except just anterior and posterior to the eye. The dark touch at the vent had also faded, but the ventral edge of the body presented the appearance of a dark stripe from vent to tail. Rusty and/or rusty brown pigment was also developed on the body and on the pigment patches on the marginal fin, towards the tail.

On April 27 (12th day) all the laboratory specimens were hovering in the water. Copepods were introduced. The fry stalked them, took careful aim, flexed their body into a Z, and snapped at them. At this stage, the yolk-sac was completely absorbed. While the snout had become wedge-shaped instead of rounded, it was not yet pike-like.

Small water fleas and also microworms were added to the dishes on this and subsequent days. It was noted that the little pike gazed intently on their prey, before snapping at it. This was quite different

from the behaviour of O-group trout, which dart rapidly and immediately at any potential prey, ejecting it if it proves unsatisfactory.

A specimen examined on April 28 (laboratory specimens, 13th day) was 14.5 mm long and only a tiny residue of yolk remained. Another specimen examined on the same day (probably later hatched) still had a fair amount of yolk left. The shape of the marginal fin was slightly altered and except for the basal portions of the rays of the dorsal and anal fins no indication of the future median fins could be seen.

Thus, in about a fortnight, the experimental lot of pike had increased in length from 8.25 mm to 14 mm, begun to feed, and absorbed their yolk-sacs. The post-larvae were not reared to the fry stage because of lack of suitable food.

The adherent phase in the pike studied lasted longer than in the Windermere pike alevins described by Frost and Kipling (1967), extending over 9 to 12 days as against not more than 6 days in Windermere. Absorption of the yolk-sac also took longer. Differences in the initial size between the Irish and Windermere alevins may be, at least in part, responsible for the difference in duration of the adherent and sac-fry stages.

Gihr illustrates later development stages. At a length of about 18 mm, the snout is much larger and the adult fins are all well mapped out, though the urostyle is still straight and there is still a marginal fin from the middle of the back to the tail, and an appreciable pre-anal fin. At a length of 35 mm, the fry is a perfect, if somewhat babyish, little pike, with typical adult snout, all fins developed, and no trace of a marginal fin.

Survival of eggs and fry

When pike eggs are hand-stripped and artificially fertilised, the percentage of unfertilised eggs is very much greater than occurs in the artificial fertilisation of salmonid eggs. This is probably because of the very small amount of milt yielded by male pike. In natural spawning, however, the percentage fertilisation appears to be high. All the pike eggs collected from spawning areas during the current investigations were fertile.

A fall in water level during the period of incubation of the eggs and the adherent phase of the larvae would probably cause considerable mortality. The present investigations do not suggest that a drop in levels in a natural lake, under Irish conditions, is likely to be extensive and rapid enough to cause significant mortality. Large and rapid changes in water level are more likely to occur in regulated lakes. There is evidence—a reduction in the numbers of O-group pike caught in traps—that in the hydro-electric reservoirs on the River Lee in County Cork a reduction in the water level in the spring in one year curtailed the production of young pike. It is not clear, however, whether this was because of mortality amongst eggs and fry

which had been spawned or because spawning was curtailed or prevented by low water levels.

During the years 1954 to 1956, the food of eels in Lough Arrow was investigated (Inland Fisheries Trust 1956, 1957). In 1955, the first eels were caught on April 7, while in 1956 the first eels were caught on March 30. No pike eggs or pike fry were found in eels, though bream eggs occurred in 7 eels and perch spawn in one eel out of 194 eels examined during the spring, while sticklebacks and perch fry occurred in 7 eels. Frost (*pers. comm.*) found no pike spawn in eels in Windermere, though eels are predators on char eggs there.

Sticklebacks and stoneloach are known to occur in the pike-spawning areas in the Irish lakes studied. Experiments carried out in aquarium tanks during the present investigations have shown that sticklebacks will readily devour the eggs and young fry of pike. Stoneloach do not prey to any significant extent on fish fry but they can locate and eat fish eggs. Predatory beetle larvae were also found in the pike-spawning areas investigated.

Laboratory studies during the current investigations showed that starvation during the early feeding stage is a major cause of mortality amongst pike fry. Suitable prey must be found quickly and in large numbers as soon as the pike are ready to feed, otherwise they quickly become weak and die. If food organisms are scarce and scattered, the pike do not get enough to satisfy their energy and growth requirements. The pike fry have no fat reserves to tide them over a lean period and consequently starvation can decimate a brood in a matter of days. Cannibalism also occurs as soon as there is sufficient difference in size between individual fry to make it possible.

Food of Young Pike

The stomach contents of some samples of young pike killed by spot treatment of nursery areas with rotenone were examined with the results set out in Table 2.

TABLE 2. Food of Irish Pike Fry.

Lake	Lough Sheelin		Lough Mask		Lough Corrib		Lough Lannagh (Castlebar)			
Date	18th May, 1963		23rd May, 1965		3rd June, 1965		30th May, 1963		10th June, 1963	
Size of pike	5.5 cm		5.2 cm (3.9—6.4 cm)		6.1 cm (5.3—6.9 cm)		6.25 cm		7.5 cm	
No. in sample	7		20		7		27		5	
Food Organisms	No. Organisms	No. Pike in which present	No. Organisms	No. Pike in which present	No. Organisms	No. Pike in which present	No. Organisms	No. Pike in which present	No. Organisms	No. Pike in which present
Cladocera **Eurycercus sp**	164	7	7	2	3	3	15	2	—	—
Simocephalus sp	—	—	24	2	6	1	7	1	—	—
Daphnia sp	—	—	—	—	—	—	21	1	—	—
Ceriodaphnia sp.	—	—	4	3	—	—	—	—	—	—
Polyphemus sp	—	—	—	—	—	—	20	1	—	—
Copepods **Cyclops sp**	—	—	5	4	—	—	—	—	—	—
Diaptomus sp	—	—	3	3	—	—	—	—	—	—
Amphipods **Gammarus sp**	2	1	7	5	11	3	70	19	9	3
Isopods **Asellus sp**	1	1	54	8	4	2	2	2	3	3
Ephemeroptera (nymphs)										
Cloëon sp	1	1	27	10	2	2	3	1	—	—
Leptophlebia sp	—	—	—	—	—	—	1	1	1	1
Caënis sp	—	—	—	—	1	1	—	—	—	—
Ephemera danica	2	1	—	—	—	—	—	—	—	—
Unidentified	1	1	—	—	—	—	17	7	—	—
Trichoptera (larvae)	—	—	—	—	—	—	—	—	1	1
Chironomid larvae	2	2	1	1	—	—	32	8	—	—
Corixids	—	—	—	—	—	—	1	1	—	—
Beetles	—	—	—	—	—	—	2	2	—	—
Hydracarina (mites)	1	1	—	—	—	—	—	—	—	—
Fish Sticklebacks	—	—	3	2	—	—	—	—	—	—
Perch fry	1	1	—	—	—	—	10	1	—	—
Pike fry	—	—	—	—	—	—	1	1	—	—
Empty		Nil		1		Nil		1		Nil

Lengths of pike fry were from snout to fork of caudal fin.

It will be seen that, in general, the larger cladocera, *Gammarus sp, Asellus sp* and *Cloëon sp* nymphs are the chief foods of Irish pike fry in the length-range 3.9—7.5 cm though chironomid larvae are occasionally important also. Even at a small size, pike fry will devour fish fry. This was established in laboratory experiments, in which post-larval pike readily attacked and ate recently-hatched perch fry. However, out of the 66 pike fry whose food is analysed in Table 2, it will be seen that only 5 have eaten small fish.* The fish eaten were:—

(a) 3 O-group 10-spined stickleback, 2.5 cm long, eaten by 2 pike of little over 5 cm long;
(b) a perch fry of 1.7 cm, eaten by a pike of 5.5 cm
and
(c) a pike of 5 cm eaten by a pike of 6 cm!

Frost (1954) found that, in Windermere, copepods and cladocera were the diet of pike up to 30 mm long. Larger fry continued to eat such large cladocera as *Eurycerus* but copepods and the smaller cladocera became much less important as food. *Gammarus, Asellus* and insect larvae were eaten in considerable amounts and fish fry became very important food items, occurring in 69 per cent of pike in the 30 to 39 mm group, 72 per cent of pike in the 40 to 49 mm group, 84 per cent of pike in the 50 to 59 mm group and 62.7 to 71.5 per cent of pike in the 60 to 200 mm group. This is in contrast to the position in the large Irish limestone trout lakes, in which fish, though eaten by small pike, are much less important than invertebrates in their diet until the pike are well into their second year. Indeed, general investigations of the food of Irish limestone lake pike show that invertebrates continue to be fairly important as food until the pike reach a weight of 1500 g.

DISCUSSION

Berg (1962) refers to spawnings of different groups of pike in L. Chud (Russian-Estonian border). One group, which enters the R. Embach under the ice, spawns in March, another group spawns in April. Water temperatures at spawning are not given, but are presumably low. He also mentions pike spawning in the Dniester, from mid-March to mid-April, at water temperatures of 3—6°C. Such pike, however, may belong to biological races adapted to spawning at relatively low temperatures.

Scandinavian workers (Svärdson, 1949; and Fabricius and Gustafson, 1958) have studied in detail the spawning of pike, both in the field and in tanks. They established that pike spawned by day (visual orientation was involved in mating); that they spawned over a bottom carpeted with dead or living vegetation over which the eggs were scattered; and that water temperatures were critical. They found that, in tanks, some spawning occurred at a temperature of 7.5°C, but not

*30 and 58 per cent, respectively, of pike fry 4.3 to 8.4 cm long taken in 1968 in L. Mask and L. Sheelin contained fry of perch and/or stickleback.

at lower temperatures. When the tank temperatures ranged between 12.5°C and 18.5°C, intense spawning activity occurred. In the pike spawning areas in L. Malären, water temperatures varied widely according to depth, sun or shade, shelter or exposure to wind and this affected the distribution of the spawning pike and whether or not spawning actually took place. Fabricius and Gustafson observe that "the most favoured spawning grounds for pike at Drottningholm are flooded meadows of sedge grass, between the shore line and the belt of Phragmites reed".

In Minnesota, Franklin and Lloyd (1963), who studied pike spawning in a slough in Lake George, reported that "spawning was observed only between 2.00 p.m. and 6.00 p.m. at temperatures which ranged from 52 to 63°F at the surface in the various areas and years. Spawning was never noted in the cattail areas . . . . but all other vegetation types were used".

In the Irish investigations, too, spawning was usually observed in the afternoon and a temperature of about 9 to 10°C appeared to be critical for the release of spawning in gravid pike. During the earlier part of the spawning season, this water-temperature is likely to be attained only on sunny days and then only during the afternoon and in sheltered, unshaded situations. Later in the spawning season, a water temperature of 10°C does not depend so much on a combination of favourable circumstances, as lake temperatures generally are rising. In the Irish lakes studied, the spawning season falls within the period February to April. It is apparent that spawning tends to be generally earlier in some lakes than in others and comparison of the 1965 with the 1966 observations shows clearly that weather conditions have a major bearing on whether spawning will be early or late in any given year. It is likely that temperatures during the final stages of ripening of the eggs must be taken into account and that a rise in water temperature to 10°C will not necessarily result in spawning if it comes suddenly after a cold spell—or even a cold night.

Healy (1956) gives the spawning season in Lough Glore, Lough Barnagrow and Lough Rea as February to April, which is in agreement with the findings for the big limestone lakes.

In the Irish lakes, the spawning of pike is almost invariably associated with high or rising lake levels. Spawning in deeper water, if it takes place, has not been observed. In 1967, when a drop in the level of Lough Derravarragh (Co. Westmeath), in the course of a drainage scheme, prevented the pike from getting into their normal spawning sites, unspawned pike were being caught as late as June. The roes of some of these pike were examined by the author and the eggs were found to be degenerating.

Pike in Irish lakes spawn in the types of situation—shallow, sheltered places with a bottom carpet of dead or living vegetation—in which spawning usually appears to occur in Scandinavia and North America. In Windermere, however, Frost and Kipling (1967) found that pike usually spawned in 2 to 3.5 metres of water where there

were stands of *Elodea, Myriophyllum* and *Nitella* and patches of *Littorella,* though some spawning occurred in water only 15—30 cm deep. Spawning in such situations is probably less critically affected by lake levels and water temperatures than is the case in the Irish lakes and Frost and Kipling found "little evidence to indicate that spawning is initiated by a particular critical temperature".

In Windermere, too, spawning appears to be later than in Ireland, occurring during April and reaching its peak in the second half of that month. Nevertheless, water temperatures during incubation of the eggs appear to be lower in Windermere than in Ireland. In the pike-spawning areas in the Irish lakes investigated the mean water temperature varied between 8°C and 12°C during the period following deposition of the eggs—the lower values occurring in the case of February spawnings (which always occur during particularly mild spells) and the higher values in the case of late March and April spawnings. The observed duration of incubation in Lough Sheelin in 1965 was 10 to 12 days. Laboratory investigations confirm for Irish pike ova the incubation requirement of about 120 day-degrees given by Huet (1960) and Schäperclaus (1961) for Continental eggs. This would give for Irish lakes a probable maximum incubation period of about 14 days and a usual minimum of about 10 days. A particularly mild, sunny spell of weather in April would, however, reduce the incubation to 8 days. The minimum incubation period recorded by Frost and Kipling (1967) in Windermere was, however, 14 days and the maximum was 21 days.

The adherent phase of larval existence, during which the pike cling to the vegetation, probably lasts, in the field, another 8—12 days under Irish conditions. For two to three weeks after hatching, therefore, there is unlikely to be any dispersal of the spawning products from the spawning areas out into the lake. Even after the free-swimming pike have begun to feed, they probably do not wander very far, but remain in the shallow, weedy spawning areas, feeding on cladocera, *Gammarus sp, Asellus sp* and the young stages of aquatic insects. There may, indeed, be no great movement from these areas until the falling water levels enforce migration from them. This is likely to happen during late May or June. This would suggest that May is probably the best time for spot rotenone treatment of the areas where pike are known to spawn, in order to kill off the fry.

The gill-net catches on the lakes studied show fluctuations indirectly associated with lake temperatures and water levels and directly with actual spawning of pike.

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Desmond McCarthy, M.Sc., former biologist with the Trust, and Miss Jacqueline Doyle, B.Sc., of the Fisheries Division of the Department of Agriculture, assisted in the collection of some of the biological material. Some of the plants were identified by the Natural History Section of the Irish National Museum, and the grass by Mr. Prendergast of the Department of Agriculture. Weather data were supplied by the Meteorological Service.

SUMMARY

(1) During the spring of 1965 water levels and maximum and minimum water temperatures were recorded in a known pike-spawning area in each of four Irish limestone lakes—Loughs Sheelin, Mask, Corrib and Arrow—and the dates on which spawning occurred were noted. Collections of ova were made from the spawning areas. The study was repeated in 1966 in the same four lakes and was also extended to Lough Ennell.

(2) In all five lakes, spawning took place in shallow, sheltered situations with a bottom carpet of dead or living vegetation consisting variously of Fiorin grass, *Agrostis stolonifera,* the grass-like rush *Juncus bulbosus* var. *fluitans, Fontinalis* moss on stones and broken reed mat lying on mud. Other plants, such as *Carex rostrata, Apium nodiflorum* and *Apium inundatum,* occurred in varying amounts in the spawning areas. Spawning took place in depths of 20 to 60 cm of water.

(3) Spawning took place only when lake levels were high or rising and when the water temperatures rose to at least 9°C or 10°C. Spawning took place by day, usually during the warmest part of the afternoon.

(4) Spawning in 1965 was delayed by severe weather at the beginning of March. The first observed spawning took place in Lough Mask on March 22, 1965, in Lough Corrib on March 30, and in Lough Sheelin on March 30. Spawning in Lough Arrow, which is usually later than in the other lakes, occurred in mid-April. In 1966, the weather was much milder and spent pike were taken in Lough Corrib as early as February 14. In Lough Ennell, spawning occurred in the study area on February 21 and March 8, 1966.

(5) Gill-net catches showed fluctuations indirectly related to lake levels and lake temperatures and reached peaks during periods when spawning was actually taking place.

(6) Irish pike eggs are 2.7 to 3.0 mm in diameter and are golden or honey-coloured, with a great many minute oil-globules distributed throughout the yolk in tiny clusters.

(7) The observed duration of incubation of pike eggs in Lough Sheelin in 1965 was 10 to 12 days. In laboratory studies the

incubation period was 6 to 11 days. It was estimated that in the field the incubation period under Irish conditions probably varies from 8 to 14 days.

(8) Newly-hatched pike larvae from small (2.75 mm) eggs incubated in the laboratory measured 8.25 mm. The range in length of Irish pike larvae on hatching was estimated to be 8.0 to 9.0 mm.

(9) The fry hang from the vegetation by means of adhesive glands on the head, for about 10 days after hatching. They then develop a swim-bladder and swim about in the water. Feeding begins 10 to 14 days after hatching, when the pike measure 13.0 to 13.5 mm. At this stage some yolk reserves still remain.

(10) The first food of Irish pike fry consists of copepods and small cladocera. From this they progress to larger cladocera (especially *Eurycercus*), amphipods, isopods and the young stages of aquatic insects. They also prey on the fry of sticklebacks and perch and will eat other pike fry smaller than themselves. In the big Irish limestone lakes, however, invertebrates are more important than fish as food of pike until well into the second year of life.

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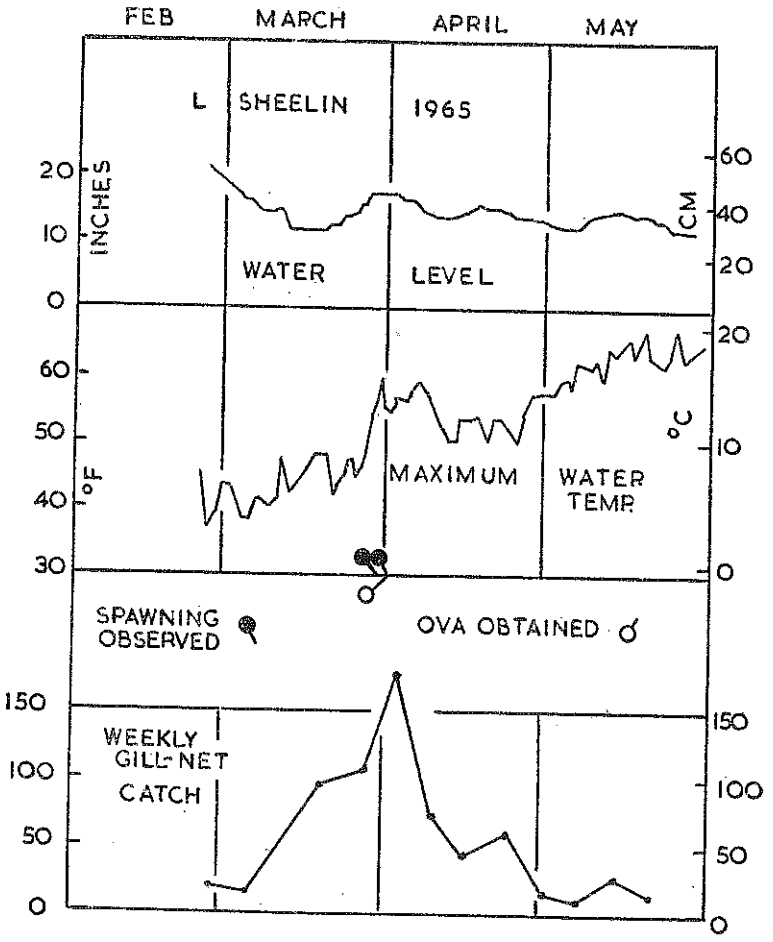

Fig. 1. Relationship between water levels, maximum water temperatures, pike spawning and weekly gill-net catches in L. Sheelin, 1965.

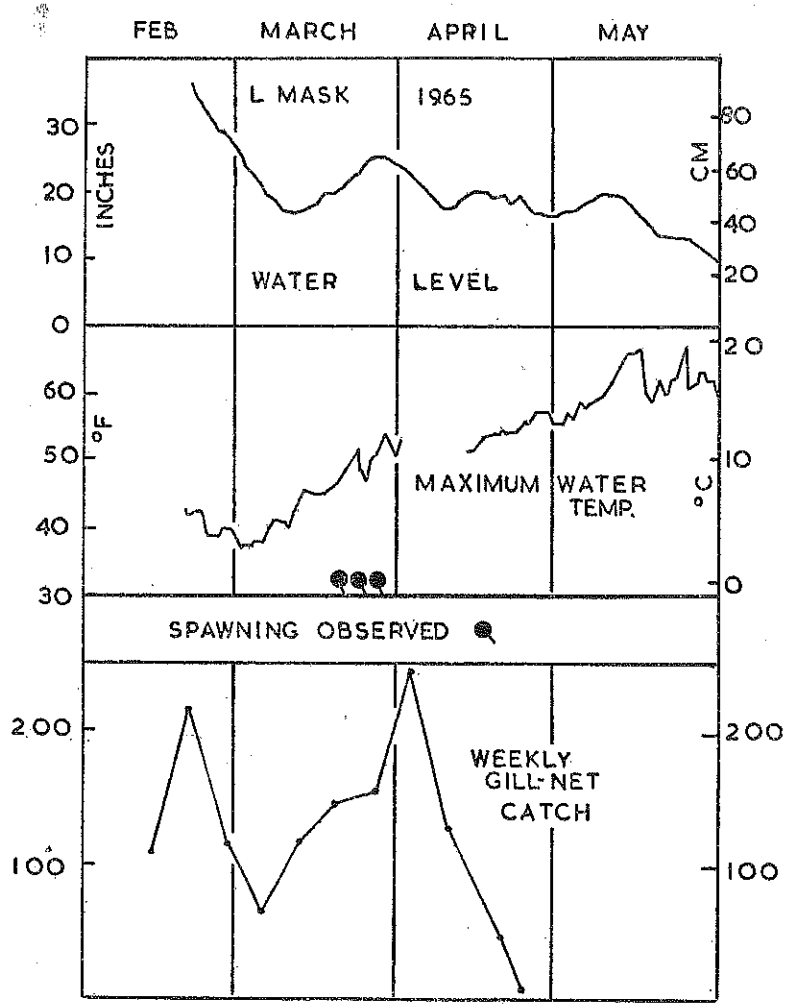

Fig. 2. Relationship between water levels, maximum water temperatures, pike spawning and weekly gill-net catches in L. Mask, 1965. (Note: no temperature readings during part of April).

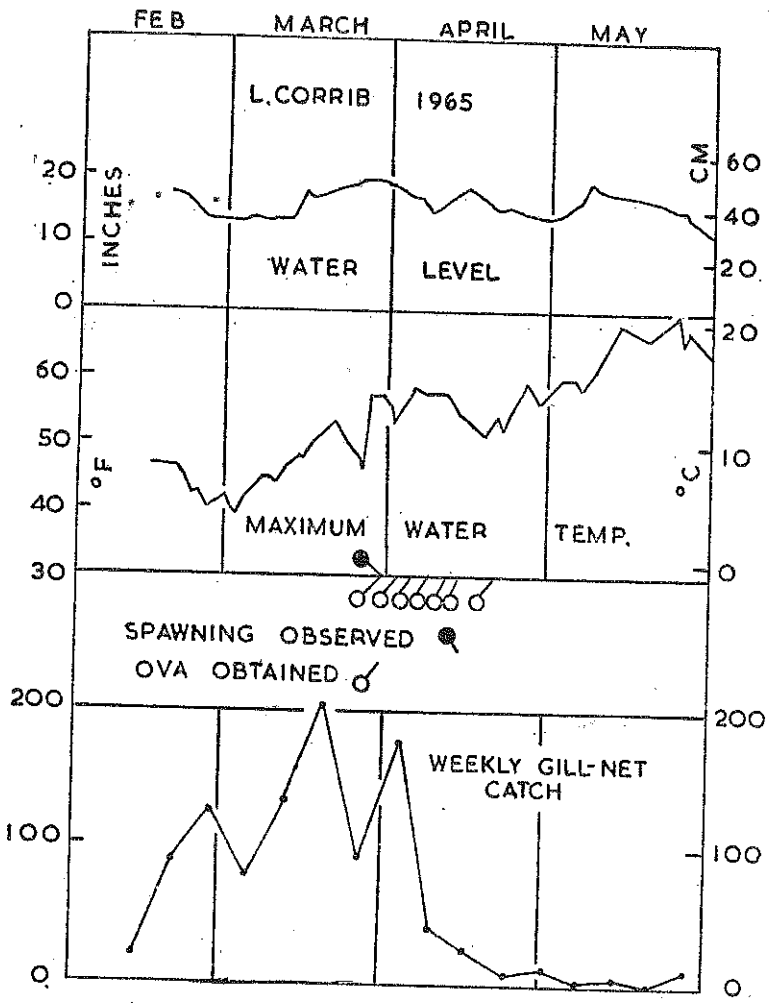

Fig. 3. Relationship between water levels, maximum water temperatures, pike spawning and weekly gill-net catches in L. Corrib (east shore) 1965.

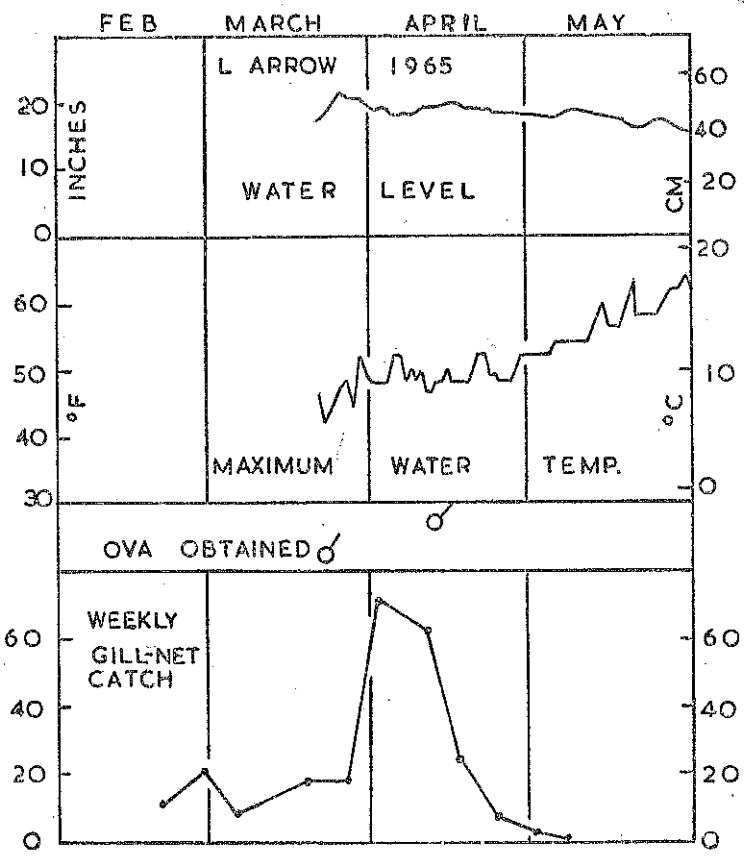

Fig. 4. Relationship between water levels, maximum water temperatures, pike spawning and weekly gill-net catches in L. Arrow, 1965.

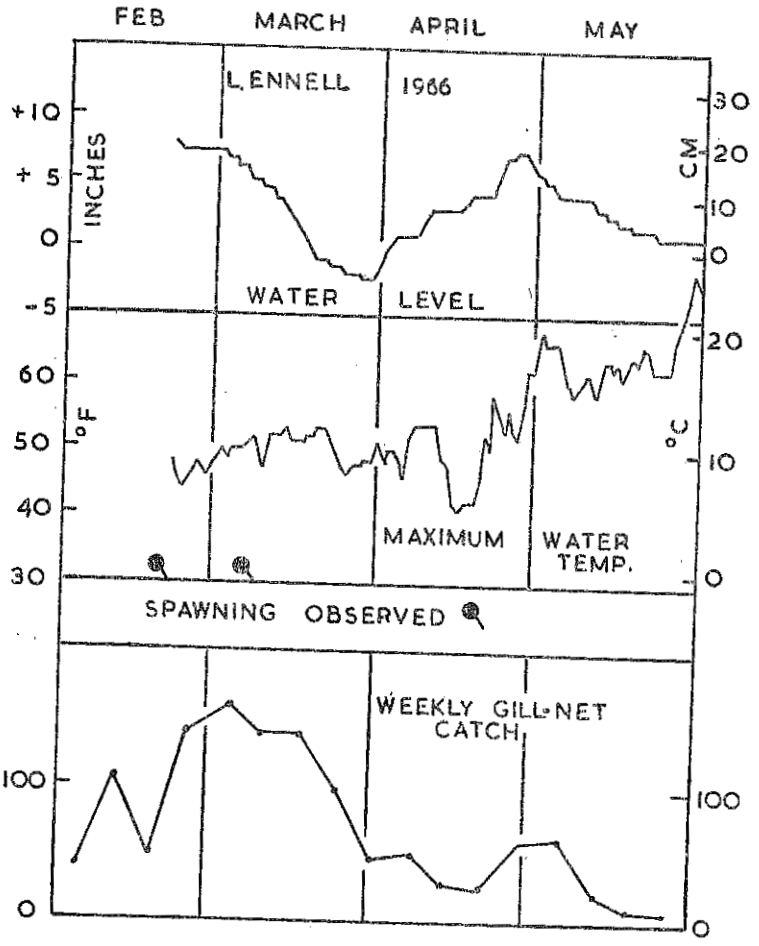

Fig. 5. Relationship between water levels, maximum water temperatures, pike spawning and weekly gill-net catches in L. Ennell, 1966. Spawning took place elsewhere in the lake, but not in the study area, on February 26, 1966.

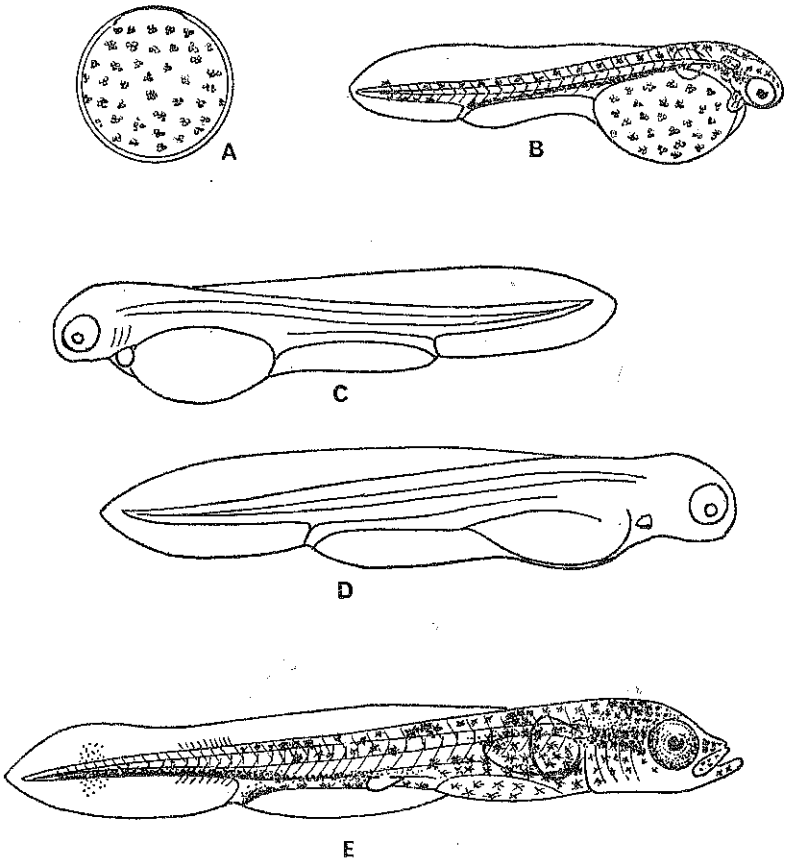

Fig. 6. Eggs and young stages of Irish pike. A, eggs, 2.75 mm. B, alevin, newly hatched, 8.25 mm. C, outline of alevin 4 days old, 10.2 mm. D, outline of alevin, 6 days old, 12 mm. E, late larva, 10 days old, 13.5 mm. All from eggs artificially fertilised at L. Owel, Co. Westmeath, April 1964. A—D, laboratory specimens. E incubated and reared at a higher temperature than laboratory specimens.